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Kinetic Alfvén wave with general loss-cone distribution function in the presence of ion and electron beam

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Abstract Dispersion relation, current and growth rate with marginal instability criteria of the kinetic Alfvén wave with general loss-cone distribution function in a low β inhomogeneous plasma in the presence of ion and electron beam, have been obtained by evaluating the trajectories of the charged particles The whole plasma is considered to consist of resonant and non-resonant particles It is assumed that non-resonant particles support the oscillatory motion of kinetic Alfvén wave while the resonant particles participate in the energy exchange with the wave The effects of steepness of loss-cone distribution in the presence of ion and electron beam are discussed on the dispersion relation, current and growth-rate of the instability The applicability of the investigation is discussed for auroral phenomena during the substorm periods

Keywords Kinetic Alfvén wave, ion and electron beam, lo

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1. Introduction

The kinetic Alfvén wave (KAW) has been invoked in association with the magnetospheric dynamics since it is successful in explaining the ultra-low-frequency (ULF) waves observed in the magnetosphere [1]. Their parallel electric fields have been considered as a possible mechanism for acceleration of electrons along field lines. Such parallel electric fields arise mainly due to the finite ion gyro-radius [2] or the finite inertial length [3] correction to the usual magnetohydrodynamic (MHD) Alfvén mode. Kinetic Alfvén wave can be excited by a MHD surface wave through a resonant mode conversion process [1,4] or driven by density gradient in an inhomogeneous plasma with $m_e/m_i < \beta < 1$ [5,6]. Observations from sounding rockets [7] and the Freja satellite [8,9] also support the existence of such waves.

In the past, it is established that auroral luminosity is due to the impact of accelerated electron beam coming towards the ionosphere and at the same event, the upflowing ion beam is also observed towards the magnetotail [10–12]. Most of the theoretical work done so far, reported that the velocity distribution function is assumed either as ideal Maxwellian or bi-Maxwellian [13], ignoring the steepness of the loss-cone feature [14]. Plasma in mirror-like devices and in the auroral region with converging magnetic field lines, may considerably depart from a Maxwellian distribution and becomes anisotropic, provided there is a relatively low degree of plasma collisionality, and in general, permits steep loss-cone distribution functions [15–24]. In this paper, we analyze how the loss-cone distribution (Dory-Guest-Harris type) influences the growth of electromagnetic instability in inhomogeneous magnetoplasma in the presence of ion and electron beam.

In the recent past, the kinetic Alfvén wave has been analyzed using particle aspect analysis in view of the auroral acceleration processes [24,25]. An alternative model usually called a particle aspect analysis [19–21,24,25], is applied which offers an advantage over the magnetohydrodynamic approach in dealing with the finite Larmor radius effect and temperature anisotropy in the inhomogeneous magnetoplasma. The basic assumptions are those of earlier work on kinetic Alfvén wave [24,25] in which plasma has been considered to consist of resonant and non-resonant

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particles and the wave growth was discussed by the energy conservation method. We have considered a kinetic Alfvén wave propagating obliquely to the constant magnetic field (z-direction), and two different potentials in the $x-z$ plane for the evaluation of the charged particle trajectory. The direction of the density gradient is along the y-axis.

2. Basic assumptions

We consider a kinetic Alfvén wave of the form [24,25]

$$\bar{E} = E_\perp + E_\parallel ,$$

where $E_\perp = -\nabla_\perp \phi, \quad E_\parallel = -\nabla_\parallel \psi$

and $\phi = \phi_1 \cos(k_\perp x + k_\parallel z - \omega t)$,

$$\psi = \psi_1 \cos(k_\perp x + k_\parallel z - \omega t),$$

where ϕ_1 and ψ_1 are assumed to be a slowly varying function of time t, and ω is the wave frequency $k_\perp$ and $k_\parallel$ define the components of wave vector k across and along the magnetic field B_0. The kinetic Alfvén wave is assumed to start at $t = 0$ when the resonant particles are undisturbed. We consider a low β collisionless plasma satisfying the conditions as mentioned below.

In the present analysis, we have considered the plane polarized kinetic Alfvén waves. Therefore, the perpendicular current is having J_Y component only.

$$V_{T\parallel i} \langle\langle \frac{\omega}{k_\parallel} \langle\langle V_{T\parallel e}, \quad \omega \langle\langle \Omega_i, \Omega_e; \quad k_\perp^2 \rho_e^2 \langle\langle k_\perp^2 \rho_i^2 \langle 1 ,$$

where $V_{T\parallel i}$ and $V_{T\parallel e}$ are the mean velocities of ions and electrons along the magnetic field, $\Omega_{i,e}$ are gyration frequencies and $\rho_{i,e}$ the mean gyro-radii of the respective species. Considering the equation of motion for the charged particles, the detailed calculations of particle trajectories in the presence of kinetic Alfvén wave have been performed by Baronia and Tiwari [24]. The density perturbations $n_1(\bar{r},t)$ due to the presence of a kinetic Alfvén wave for the resonant and non-resonant particles is evaluated.

3. Distribution function

To determine the dispersion relation and the growth-rate, we consider a bi-Maxwellian plasma with density distribution

$$N(y,\bar{V}) = N_0\left[1-\epsilon\left(y+\frac{V_x}{\Omega}\right)\right] \cdot f_\perp(V_\perp) f_\parallel(V_\parallel), \quad (1)$$

where ϵ is a small parameter of the order of inverse of the density gradient scale length. We consider a general distribution function for $f_\perp(V_\perp)$ as [14,15,20,23,24]

$$f_\perp(V_\perp) = \left[V_\perp^{2J} / \pi V_{T\perp}^{2(J+1)} J!\right] \exp\left(-V_\perp^2/V_{T\perp}^2\right) \quad (2a)$$

and $f_\parallel(V_\parallel)$ which is defined by the drifting Maxwellian [21]

$$f_\parallel(V_\parallel) = \left(\frac{1}{\sqrt{\pi} V_{T\parallel}}\right) \exp\left\{-m\left(V_\parallel - V_{Dt}\right)^2 / 2T_\parallel\right\} \quad (2b)$$

where J is the distribution index and measures the steepness of the loss-cone feature [21,23,24]. In the case of $J = 0$ this represents a bi-Maxwellian distribution and for $J = \infty$ this reduces to the Dirac delta function [20]. $V_{T\parallel}^2 = 2T_\parallel/m$ and $V_{T\perp}^2 = (J+1)^{-1} 2T_\perp/m$ are the squares of parallel and perpendicular thermal velocities with respect to the external magnetic field. V_{Dt} defines the beam velocity of the particles

4. Dispersion relation

The integrated perturbed density for non-resonant particles is given as

$$\tilde{n}_{i,e} = \int_0^\infty 2\pi V_\perp dV_\perp \int_{-\infty}^{\infty} dV_\parallel n_{i,e}(\bar{r},t). \quad (3)$$

We use the expression of $n_{i,e}(\bar{r},t)$ for non-resonant particles which has been evaluated by Baronia and Tiwari [24] as

$$n_1(\bar{r},t) = N(V) \sum_{-\infty}^{\infty} J_n(\mu) \sum_{-\infty}^{\infty} J_l(\mu)$$

$$\times \frac{q}{m}\left[\left\{\phi_1 - \frac{V_\parallel k_\parallel}{\omega}(\phi_1 - \psi_1)\right\}\left\{\frac{k_\perp^2}{a_n^2} - \frac{\Omega^2 V_d k_\perp m}{\Lambda_n a_n^2 T_\perp}\right\}\right.$$

$$\left. + \frac{k_\parallel^2}{\Lambda_n^2}\left\{\psi_1 + \frac{n_1}{\alpha_1}\frac{V_\perp k_\perp}{\omega}(\phi_1 - \psi_1)\right\}\right] \cos\xi_{nl}, \quad (4)$$

where V_d is the diamagnetic drift velocity which is defined by

$$V_d = \frac{T_\perp}{m\Omega} \frac{1}{N} \frac{\partial N}{\partial y}.$$

and $V_d = 0$ represents the homogeneous plasma, $T_\perp$ is the perpendicular temperature, q is the charge and m is the mass of the particle,

and $\Lambda_n = k_\parallel V_\parallel - \omega + n\Omega; \mu = (k_\perp V_\perp / \Omega)$,

$$\xi_{nl} = (l-n)(\theta - \Omega t) + k_\perp x + k_\parallel z - \omega t ,$$

$$a_n^2 = \Lambda_n^2 - \Omega^2 ,$$

θ is the initial phase of velocity at $t = 0$.

In view of the approximations, the dominant contribution comes from the term $n = 0$. The resonant criterion is given by $k_\parallel V_\parallel - \omega = 0$. Therefore, this resonant condition means that the electrons see the wave independent of t in the particles frame. The particles satisfying the above condition are called resonant. $J_n(\mu)$ and $J_l(\mu)$ are Bessel's functions which arise from the different periodical variation of charged particles trajectories. The term represented by Bessel's functions shows the reduction of the field intensities due to finite gyro-radius effect. With the help of eqs. (1) and (4) we find the average densities for inhomogeneous plasma as

$$\bar n_i = \frac{N_0 e}{m_i}\left[-\frac{k_\perp^2\phi}{\Omega_i^2} + \frac{k_\parallel^2\psi}{\left(\omega - k_\parallel V_{Di}\right)^2} + \frac{V_d' k_\perp m_i}{T_{\perp i}\left(\omega - k_\parallel V_{Di}\right)}\right.$$

$$\left. 1 - \frac{1}{2}k_\perp^2\rho_i^2(J+1)\right], \tag{5}$$

$$4\pi e V_{T\parallel e}^2 \quad \psi \tag{6}$$

where $V_{T\parallel e}^2$ is the square of thermal velocity along the ambient magnetic field. For Maxwell's equation, we use the quasi-neutrality condition [24–26]

$$\bar n_e = \bar n_i$$

and we get the relation between ϕ and ψ as

$$\phi = \frac{\Omega_i^2}{k_\perp^2} \quad \frac{}{\omega_{pi}^2 V_{T\parallel e}^2 A} \quad \frac{k_\parallel^2}{\left(\omega - k_\parallel V_{Di}\right)^2}$$

$$\frac{V_d' k_\perp \Omega_i^2 m_i}{T_{\perp i} k_\perp^2\left(\omega - k_\parallel V_{Di}\right)} \quad \psi \tag{7}$$

Using perturbed ion and electron densities $\bar n_i$ and $\bar n_e$ and Ampere's law in the parallel direction [24–26], we obtain the equation

$$\frac{\partial^2}{\partial z^2}\nabla_\perp^2(\phi - \psi) = \frac{4\pi}{c^2}\frac{\partial^2}{\partial t}J_z, \tag{8}$$

where $J_z = e\int_0^\infty 2\pi V_\perp dV_\perp \int_{-\infty}^{\infty} dV_\parallel\left[\left(N(\bar V)u_z(\bar r,t) + V_\parallel n_1(\bar r,t)\right)_i\right.$

$$\left.\left(N(\bar V)u_z(\bar r,t) + V_\parallel n_1(\bar r,t)\right)_e\right]$$

The expression for $u_z(\bar r,t)$ is calculated by Baronia and Tiwari [24] which is given as

$$u_z(\bar r,t) = -\frac{q}{m}\left[\psi_1 k_\parallel + \frac{V_\perp k_\parallel k_\perp}{\omega}\left(\phi_1 - \psi_1\right)\frac{n_1}{\alpha_1}\right.$$

$$\sum J_n(\mu)\sum J_l(\mu)$$

$$\times\left[\cos\xi_{nl} - \delta\cos(\xi_{nl} - \Lambda_n t)\right], \tag{9}$$

where $\delta = 0$ for the non-resonant particles and $\delta = 1$ for the resonant one.

J_z is the current density which is contributed by first-order perturbations of density and velocity. With the help of eqs (7) and (8) we obtain the dispersion relation for the kinetic Alfvén wave in inhomogeneous plasma as

$$\frac{\omega_i^2}{k_\parallel^2 c_s^2 A} - \frac{\omega_e\omega A}{k_\parallel^2 v_A^2}D_d \quad \frac{k_\perp^2\omega_i^2}{k_\parallel^2\Omega_i^2}D_d$$

$$\frac{\omega_{pi}^2\omega_i^2 A}{c^2\Omega_i^2 k_\parallel^2}\left(\frac{T_{\parallel i}}{m_i}\right)\cdot\left[\frac{}{\omega_{pi}^2 V_{T\parallel e}^2 A} - \frac{k_\parallel^2}{\omega_i^2}\right.$$

$$\frac{V_d' k_\perp m_i\omega}{T_{\perp i}\omega_i^2}D_d \qquad \frac{\omega A k_\parallel(V_{Di} - V_{De})}{k_\parallel^2 v_A^2}D_d$$

$$+\frac{V_d' T_{\parallel i}k_\parallel V_{Di}}{c^2 k_\perp T_{\perp i}}\left(\frac{\omega_{pe}^2}{k_\parallel^2 V_{T\parallel e}^2} + \frac{A\omega_{pi}^2}{}\right. \tag{10}$$

where $\omega_i = \omega - k_\parallel V_{Di}$, $\omega_e = \omega - k_\parallel V_{De}$ (10a)

$$A = \left(1 - \frac{1}{2}k_\perp^2\rho_i^2(J+1)\right),$$

$$D_d = \left(1 - \frac{V_d' k_\perp \Omega_i^2 m_i}{T_{\perp i}k_\perp^2\omega}\right.$$

and $$c_s^2 = \frac{\omega_{pi}^2 V_{T\parallel e}^2}{\omega_{pe}^2}$$

is the square of ion-acoustic speed and

$$v_A^2 = \frac{c^2\Omega_i^2}{\omega_{pi}^2}$$

is the square of Alfvén speed V_{Di} and V_{De} are the beam velocities of ions and electrons respectively. The dispersion relation of the kinetic Alfvén wave reduces to that derived by Hasegawa and Chen [27], Baronia and Tiwari [24] under the approximation, $V_d' = 0$, $J = 0$, $V_{Di} = 0$, $V_{De} = 0$ and $I_0(\lambda_i)$ $\exp(-\lambda_i) \sim 1 - \lambda_i$, for $\lambda_i = \frac{1}{2}k_\perp^2\rho_i^2 < 1$ as we have applied. $I_0(\lambda_i)$ is the modified Bessel function.

5. Current density

Since the average value of current vanishes which is contributed by first-order perturbations of density and velocity due to their periodical variations, we evaluate the average current which is the second-order perturbation. To evaluate the perturbed current density we use the following set of equations

$$\bar J_{i,e} = \int_0^\lambda ds\int_0^\infty 2\pi V_\perp dV_\perp\int^\infty dV_\parallel e$$

$$\times\left[(N + n_1)(\bar V + \bar u) - N\bar V\right]_{i,e}$$

and $$\bar J = \bar J_i - \bar J_e. \tag{11}$$

With the help of eqs (1), (4) and (9) we obtain

$$J_{xe} = -\frac{N_0 e^3 k_\perp k_\parallel^2 \lambda}{2 m_e^2 \Omega_e^2}\left[-\frac{\psi_1(\phi_1-\psi_1)}{\omega} - \frac{2\omega_e}{k_\parallel^2 V_{T\parallel e}^2}\psi_1\phi_1 + \frac{2\omega_e^2}{\omega k_\parallel^2 V_{T\parallel e}^2}\psi_1(\phi_1-\psi_1)\right], \quad (12)$$

$$J_{xi} = \frac{N_0 e^3 k_\perp k_\parallel^2 \lambda}{2 m_i^2 \Omega_i^2}\left[\frac{\phi_1\psi_1}{\omega_i}\right]\left(1 - k_\perp^2\rho_i^2(J+1)\right). \quad (13)$$

Similarly for the current in the z-direction,

$$J_{ze} = \frac{N_0 e^3 \psi_1 k_\parallel \lambda}{2 m_e^2}\left[-\frac{(\phi_1-\psi_1)}{\omega} - \frac{2\omega_e}{k_\parallel^2 V_{T\parallel e}^2}\phi_1 + \frac{2\omega_e^2}{\omega k_\parallel^2 V_{T\parallel e}^2}(\phi_1-\psi_1)\right] \times \frac{k_\perp^2}{\Omega_e^2} - \frac{4\omega_e}{k_\parallel^2 V_{T\parallel e}^4}\psi_1 \quad (14)$$

$$J_{zi} = \frac{N_0 e^3 k_\parallel \lambda \psi_1}{2 m_i^2}\left[\frac{k_\perp^2\phi_1}{\Omega_i^2\omega_i} - \frac{\psi_1}{\omega_i V_{T\parallel i}^2}\right] \times \left(1 - k_\perp^2\rho_i^2(J+1)\right). \quad (15)$$

Substituting eqs (12) and (13) in eq. (11) we obtain

$$J_x = -\frac{\psi_1 e k_\perp k_\parallel^2 \lambda}{8\pi}\left[\frac{\omega_{pe}^2}{m_e \Omega_e^2}\left\{\frac{(\phi_1-\psi_1)}{\omega} + \frac{2\omega_e}{k_\parallel^2 V_{T\parallel e}^2}\phi_1 - \frac{2\omega_e^2}{\omega k_\parallel^2 V_{T\parallel e}^2}(\phi_1-\psi_1)\right\} - \frac{\omega_{pi}^2\phi_1}{m_i\Omega_i^2\omega_i} \times \left(1 - k_\perp^2\rho_i^2(J+1)\right)\right], \quad (16)$$

$$J_z = \frac{e\psi_1 k_\parallel \lambda}{8\pi}\left[\frac{\omega_{pe}^2}{m_e}\left\{\left(\frac{(\phi_1-\psi_1)}{\omega} + \frac{2\omega_e}{k_\parallel^2 V_{T\parallel e}^2}\phi_1 - \frac{2\omega_e^2}{\omega k_\parallel^2 V_{T\parallel e}^2}(\phi_1-\psi_1)\right)\frac{k_\perp^2}{\Omega_e^2} + \frac{4\omega_e}{k_\parallel^2 V_{T\parallel e}^4}\right\} - \frac{\omega_{pi}^2}{m_i\omega_i}\left\{\frac{k_\perp^2\phi_1}{\Omega_i^2} + \frac{\psi_1}{V_{T\parallel i}^2}\right\}\left(1 - k_\perp^2\rho_i^2(J+1)\right)\right] \quad (17)$$

where ω_i and ω_e are given by eq. (10a).

In the evaluation of the current densities, it was assumed that the field-aligned and perpendicular currents are due to an electromagnetic kinetic Alfvén wave and the contribution due to diamagnetic drift was neglected.

6. Growth rate

The wave energy density per unit wavelength W_w is the sum of pure field energy and the changes in energy of the non-resonant particles $W_{i,e}$. It is observed that the wave energy is contained in the form of the oscillatory motion of the non-resonant electrons [20,28]. Thus,

$$W_w \approx W_e \approx \frac{\lambda k_\parallel^2 \psi_1^2 \omega_{pe}^2}{16\pi k_\parallel^2 (T_{\parallel e}/m_e)} \quad (18)$$

The resonance energy W_r of the electrons per unit wavelength which is obtained as [24]

$$W_r = \pi^{1/2}\frac{\lambda k_\parallel^2 \psi_1^2 \omega_{pe}^2}{8\pi}\frac{\omega t}{k_\parallel^2 (T_{\parallel e}/m_e)}\frac{\left[(\omega - k_\parallel V_{De}) - k_\perp V_d^e (T_{\parallel e}/T_{\perp e})\right]}{k_\parallel (2T_{\parallel e}/m_e)^{1/2}}\exp\left[-m_e(\omega - k_\parallel V_{De})^2/2T_{\parallel e}k_\parallel^2\right], \quad (19)$$

where $\omega_{pi,e}^2 = 4\pi N_0 e^2/m_{i,e}$.

Using the law of conservation of energy, we calculate the growth rate of the drift kinetic Alfvén wave by

$$\frac{d}{dt}(W_W + W_r) = 0, \quad (20)$$

which provides

$$\gamma = (1/\psi_1)(d\psi_1/dt) = \pi\omega(T_{\parallel e}/m_e)\left\{\frac{k_\perp V_d^e}{k_\parallel (T_{\perp e}/m_e)} \times f_{\parallel e}(\omega/k_\parallel) - f'_{\parallel e}(\omega/k_\parallel)\right\}$$

With the help of eqs. (18)–(20), we found the growth rate of drift kinetic Alfvén wave as

$$\gamma/\omega = \pi^{1/2}\frac{(\omega - k_\parallel V_{De})}{k_\parallel V_{T\parallel e}}\frac{T_{\parallel e}k_\perp V_d^e}{T_{\perp e}(\omega - k_\parallel V_{De})}\exp\frac{(\omega - k_\parallel V_{De})^2}{k_\parallel^2 V_{T\parallel e}^2} \quad (21)$$

where $V_{T\perp,\parallel}^2 = (2T_{\perp,\parallel}/m)$; V_d^e represents electron diamagnetic drift velocity and the value of ω for the drift kinetic Alfvén wave has to be substituted. In the case $V_{De} = 0$ we recover the growth rate as derived by Baronia and Tiwari [24,25].

7. Marginal instability

For the marginally stable condition, we must have $\gamma = 0$. We then arrive at the result

$$V_{De} = \left|\omega - \frac{T_{\parallel e}}{T_{\perp e}}k_\perp V_d^e\right. \quad (22)$$

which shows that the electron beam may be also source of generation of kinetic Alfvén wave in spite of drift due to density inhomogeneity. If $V_d^e = 0$, then beam velocity above the phase velocity of the wave may cause the wave generation.

8. Results and discussion

In the present analysis, the expressions for the dispersion relation, current and growth rate are evaluated in the presence of ion and electron beam, and the steepness of the loss-cone. The following parameters for the auroral acceleration region [10,24,25] are used to evaluate the dispersion relation, current and growth-rate.

$B_0 = 4300\ nT$, $\Omega_i = 412\ \mathrm{s}^{-1}$, $KT_{\parallel i} = 1$ keV,
$KT_{\parallel e} = 10$ keV, $V_d^e = 200$ cm/sec, $\omega_{pi}/\Omega_i = 10$,
$K_F = 5 \times 10^{-11}\ \mathrm{cm}^{-1}$.

Figure 1 show the relation between wave frequency ω *versus* perpendicular wave number $k_\perp\rho_i$ for different values

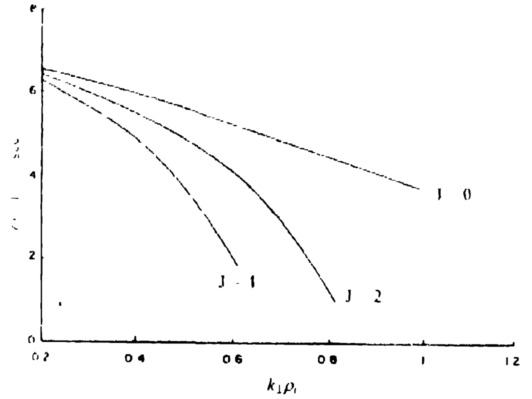

Figure 1. Frequency (ω) *versus* perpendicular wave number ($k_\perp\rho_i$) for different distribution index J, $V_{Di} = -1 \times 10^6$ cm/sec, $V_{De} = 1 \times 10^8$ cm/sec

of J at fixed V_{Di} and V_{De}. It is noticed that wave frequency ω is decreasing with increasing values of $k_\perp\rho_i$ and J, which may be due to the decrease of ion drift velocity in the presence of steep loss-cone distribution function. The steepness of the loss-cone distribution index appears through the ion gyro-radius effects which actually determines the wave frequency.

Figure 2 shows the variation of growth-rate γ/ω with $k_\perp\rho_i$ for different values of J at fixed V_{Di} and V_{De}. It is seen that higher distribution index enhances the growth-rate and permits a lower frequency for emission. At higher $k_\perp\rho_i$ there is no frequency band for the higher J. Thus mirror-like configuration of the magnetospheric structure with a steep distribution index may be unstable for the electromagnetic kinetic Alfvén wave emission. The increase of J narrows down the emission band and the wave can be generated for the lower values of $k_\perp\rho_i$.

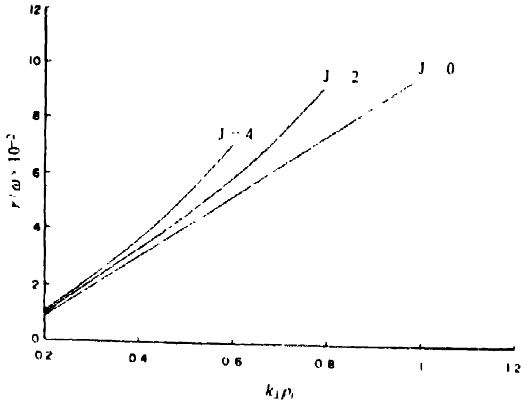

Figure 2. Growth rate (γ/ω) *versus* perpendicular wave number ($k_\perp\rho_i$) for different distribution index J, $V_{Di} = -1 \times 10^6$ cm/sec, $V_{De} = 1 \times 10^8$ cm/sec

Figures 3 and 4 exhibit the variation of wave frequency ω and growth-rate γ/ω with $k_\perp\rho_i$ at different temperature anisotropies $T_\perp/T_\parallel$ for $J = 2$ at fixed V_{Di} and V_{De}. The effect of temperature anisotropies is to enhance the wave frequency

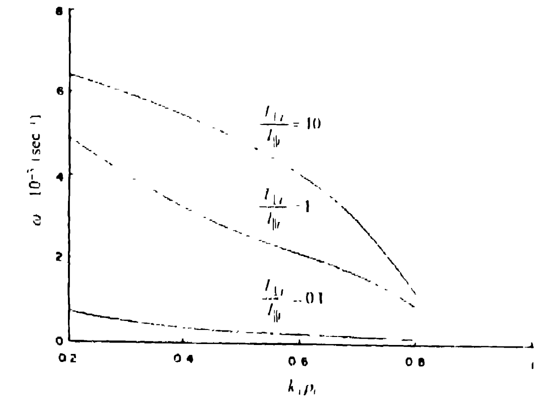

Figure 3. Frequency (ω) perpendicular wave number ($k_\perp\rho_i$) for different temperature anisotropy $T_\perp/T_\parallel$, J = 1 × 10^8 cm/sec, $V_{Di} = -1 \times 10^6$ cm/sec

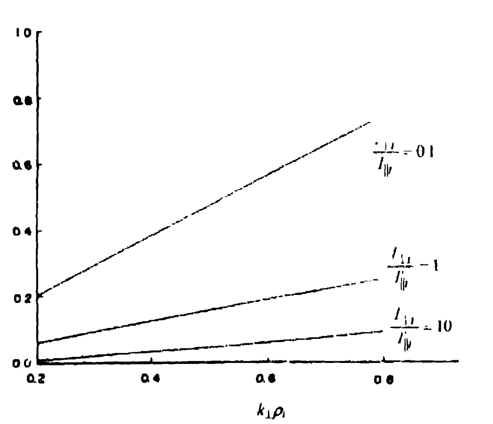

Figure 4. Growth rate (γ/ω) *versus* perpendicular wave number ($k_\perp\rho_i$) for different temperature anisotropy $T_\perp/T_\parallel$, $J = 2$, $V_{De} = 1 \times 10^8$ cm/sec, $V_{Di} = -1 \times 10^6$ cm/sec

and to reduce the growth-rate. It means the wave loses energy by wave particle interaction by transferring the energy to the particles by Landau damping. The destabilizing effect due to steepness of loss-cone and the stabilizing effect due to anisotropy are predicted.

Figure 5 shows the increase of field-aligned current J_z with the increase of distribution index J and Figure 6 exhibits an increase of perpendicular current J_x with J at fixed values of V_{Di} and V_{De}. Both the figures predict that the currents in parallel perpendicular directions are generated by the kinetic Alfvén wave which couples the perpendicular and parallel potential drop along the auroral field lines in the acceleration region. The reversal of the field-aligned current with perpendicular wave number at higher J values is shown in Figures 5 and 6 which may be due to the coupling of potential drops along and perpendicular to the magnetic field and the mirroring effects at higher J. Thus, perpendicular and parallel electric fields coupled by the kinetic Alfvén wave also have their effect on the current pattern.

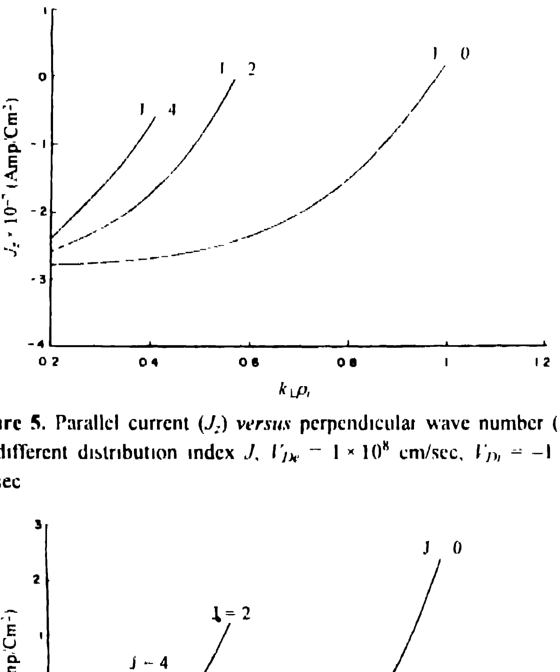

Figure 5. Parallel current (J_z) *versus* perpendicular wave number ($k_\perp \rho_i$) for different distribution index J, $V_{De} = 1 \times 10^8$ cm/sec, $V_{Di} = -1 \times 10^6$ cm/sec

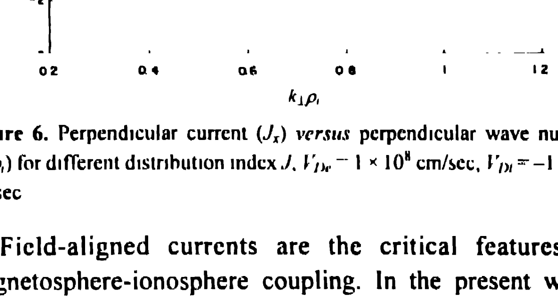

Figure 6. Perpendicular current (J_x) *versus* perpendicular wave number ($k_\perp \rho_i$) for different distribution index J, $V_{De} = 1 \times 10^8$ cm/sec, $V_{Di} = -1 \times 10^6$ cm/sec

Field-aligned currents are the critical features of magnetosphere-ionosphere coupling. In the present work, we have attributed their origin to plasma density inhomogeneity through the generation of kinetic Alfvén waves as well as beam effects of the magnetosphere. In the sub-auroral region II, the field-aligned current system is commonly attributed to pressure driven current sources [29]. When changes in the magnetospheric pressure take place suddenly (for example, when a magnetospheric substorm expansion take place), the plasma density-changes will lead to a new field aligned current distribution which will transiently be carried out to the ionosphere along the field by KAW that will bounce back and forth on closed field lines.

Destabilizing effects due to the steep loss-cone on different instabilities are also reported in various papers [20,21,23,24]. The steep loss-cone structures are analogous to mirror like devices with higher mirror ratio which may accelerate the charged particles moving perpendicular to the magnetic field. Thus, more energetic particles may be available to provide energy to the wave by wave-particles interactions. The sharp density gradients may appear owing to the particle precipitation in the auroral zone [10]. Energetic particles may create a temperature anisotropy during the substorms periods which may also control the kinetic Alfvén wave emission.

The theory may be useful to study the electrodynamics of auroral ionospheric region. The presence of field-aligned current in the auroral ionosphere can permit short wavelength drift kinetic Alfvén wave instabilities to grow at lower altitudes. The converging magnetic field lines in the higher latitude auroral ionosphere may be considered suitable for the use of generalized distribution functions. Up flowing ion beam and down coming electron beam along with energetic particles may excite kinetic Alfvén wave. The study may also be useful for the experimental devices with current carrying plasma [21].

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